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RADIATION EFFECTS ON SILVER AND ZINC  
BATTERY ELECTRODES. II

Interim Report

July 1965 to October 1965

Prepared for Jet Propulsion Laboratory

Under Contract No. 951109

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*under NASW 7-100*

**By**

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## I. SUMMARY

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The study of the effects of radiation on silver and zinc electrodes was continued with specific attention being given to the silver electrode. Cadmium counter electrodes were used with the silver electrodes in the study pending the availability of suitable zinc electrodes.

Material losses from irradiated ( $7.2 \times 10^7$  rads) silver electrodes of 3.0 gm total weight averaged 60.2, 77.7 and 52.9 mg at 90, 60 and 30% state of charge, respectively; the corresponding losses for the control silver electrodes were 11.9, 22.7 and 22.4 mg. The predominant silver species detected in the precipitated material from the irradiated cells was silver metal.

The effects of radiation on electrode capacity appear to be no larger than 5 to 10% in the dose range studied ( $\approx 10^8$  rad ( $H_2O$ )); both capacity increases (at 90% and 60% state of charge) and decreases (at 30% state of charge) were observed. Considerable scatter was observed in the silver electrode capacity data. Both the irradiated and the control cell ended up by cycling about an  $Ag_2O/AgO$  transition, independent of the state of charge at the beginning of the experiment. Further investigation will be required to confirm and explain this behavior.

Hydrogen evolution occurred during cell irradiation; none was formed in the control cell. A pressure build-up was observed in irradiated cells; the control cells showed both small increases and decreases in pressure.

*Author*

## II. INTRODUCTION

Storage batteries are used as a source of auxiliary power on almost all space vehicles. These vehicles are exposed to various types of radiation from either cosmic rays or the Van Allen radiation belt. The flight of the SNAP-10A exposed the batteries on board to rather high levels of radiation. During the 43-day life of that mission the batteries, both Ni-Cd and Ag-Zn, received about  $10^6$  rads ( $H_2O$ ) total irradiation.

Previous studies<sup>(1)</sup> have shown that radiation damage to the Ni-Cd system starts at about  $10^6$  rads. Therefore, it appeared imperative that a similar study be made on the important Ag-Zn system.

The first results of this study of the Ag-Zn system have been reported.<sup>(2)</sup> Excessive material loss from the zinc electrodes was encountered during capacity measurements. To avoid these complications, this study is concentrating initially on the silver (oxide) electrode (a cadmium counter electrode is employed).

Principal effects reported previously were (1) a loss of material from the silver electrode during irradiation, and (2) the precipitation of silver, during irradiation, from a KOH solution previously or currently in contact with a charged silver electrode.



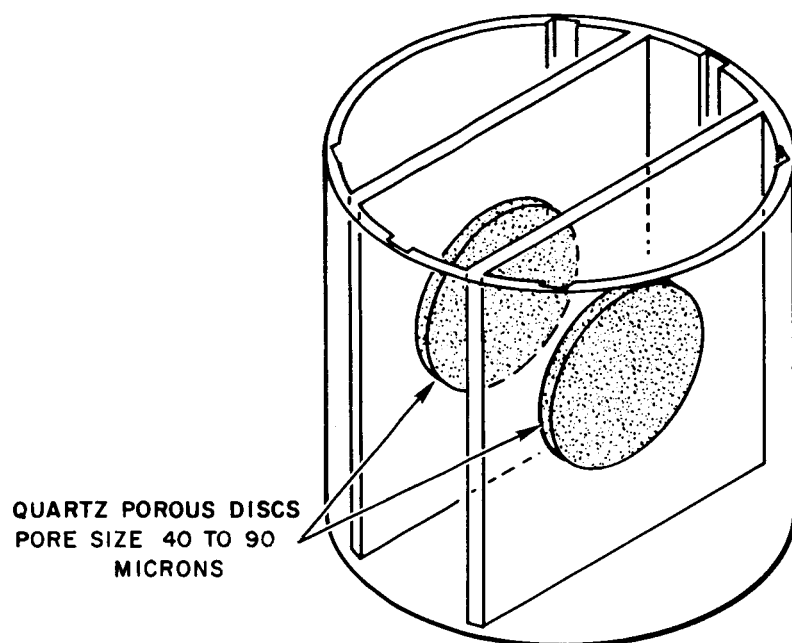
### III. EXPERIMENTAL

#### A. CELL DESIGN

The features of the stainless steel cased cell being used remain essentially as reported previously.<sup>(1,2)</sup> However, the following modifications were incorporated. The C.E.C. Model 2-316 (range =  $\pm 12.5$  psig) pressure transducer was replaced by Model 4-316 (range =  $\pm 12.5$  psig) and then by 4-312 (range =  $\pm 25$  psig) when they were rendered inoperative by thermal and radiation damage. In all cases the recorder circuitry feed from the transducers was adjusted to a sensitivity of 1 mv/psig.

The stainless steel needle valves, attached to the top of the cell to permit removal of gases for chromatographic analysis, were replaced (Run #CG-19 and after) by Swagelok Quick-Connects for ease of gas handling and to avoid gas leakage during valve operation.

The three compartment polystyrene cell liner (Figure 1) was the one principally used this quarter (Runs #CG-10 through CG-20), although a two compartment quartz liner<sup>(1)</sup> was also employed (Run #CG-21). Polystyrene was employed to reduce  $\text{SiO}_2$  contamination of material precipitated from electrodes. In this polystyrene liner, the electrolytic connection between the compartments is through porous quartz discs, 30 mm dia. x 3.2 mm thick, of 40 to 90 micron pore size. These discs are cemented into polystyrene plates which, in turn, are cemented into the cylindrical outer shell. These discs proved to be readily attacked by the 40% KOH electrolyte and fell apart after four or five runs. Also, the  $\text{SiO}_2$  falling from them during testing contaminated the material lost from the electrodes,



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Figure 1. Polystyrene Cell Liner

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3a

necessitating a correction of this material loss for  $\text{SiO}_2$ . Unfortunately, no substitute for the porous quartz is available. The silver electrode is mounted in the center compartment, with two parallel connected (cadmium) counter electrodes in the outer compartments.

#### B. CIRCUITRY FOR MEASUREMENT AND CONTROL

The circuitry employed for automatic measurement of electrode capacity and for automatic control of current for cycling remains unchanged from that reported previously.<sup>(2)</sup>

#### C. GAMMA RADIATION SOURCES

The  $\text{Co}^{60}$  gamma source used this quarter was the same as the one employed during the previous report period.<sup>(2)</sup> A re-assessment of its output showed that due to the decay of  $\text{Co}^{60}$ , the source is presently rated at  $1.1 \times 10^6$  rads ( $\text{H}_2\text{O}$ ) per hour (rather than  $1.2 \times 10^6$ , as previously reported<sup>(2)</sup>). Irradiation periods of from 65 to 89 hours were employed during the first two quarters of this program, resulting in total dosages ranging from  $7.2 \times 10^7$  to  $9.8 \times 10^7$  rads.

#### D. ELECTRODE SPECIFICATIONS

The silver electrodes (from Yardney Electric Co.) used were the same as those used previously. They had an 0.8 amp hour (nominal) capacity, and measured 41 x 35 mm by 0.4 mm thick. Their weight (exclusive of the current lead) was approximately 3.0 gm. To obtain an adequate number of capacity measurements in a limited time period and to insure that the

silver electrode limited the cell capacity, at first one-third and later one-half of the silver electrode was cut away from the side of the electrode prior to use.

The cadmium electrodes employed (2mm thick, of nominal 0.5 AH capacity) were taken from Union Carbide N75 sealed nickel-cadmium batteries. For use, they were cut to 41 x 35 mm to fit the cell liner. The capacity of the cut electrode was about 0.45 AH.

#### E. ELECTRODE TESTING PROCEDURES

The initial charging procedure for the silver electrodes reported previously<sup>(2)</sup> was modified, starting with Run #CG-10. In this new charging and pre-conditioning procedure, the silver electrode and the two cadmium counter electrodes were placed into the polystyrene liners and sealed into the stainless steel cases. The cell was charged at 100 ma for 8 hours to beyond full capacity, and then placed on the standard automatic cycling regime<sup>(2)</sup> for a 24-hour period. The 100 ma current was retained for the cut electrodes resulting in an increase from a 5-hour rate to first a 3.3-hour and then a 2.5-hour rate. This higher rate is reported to have no significant effect on the behavior (properties or capacity) of the silver electrode.

Subsequent capacity measurements, testing, and analytical procedures were essentially unchanged from those reported previously.<sup>(2)</sup> A typical set of charge and discharge curves used for silver electrode capacity

measurement is shown in Figure 2. Three features of these curves should be pointed out. First, the capacity on discharge nearly equals that on charge for both cells (nearly equal charge and discharge times). Second, the transition between the high and low voltage plateaus occurs at a higher state of charge during discharge than during charge. Third, the long overcharge portion of the charge curve (beyond 300 minutes to 470 minutes) was employed to make certain that the silver and not the cadmium electrodes limited the cell capacity.

Starting with Run #CG-10, the electrolyte employed was Baker Analyzed Reagent 40% potassium hydroxide solution having a carbonate content of 0.05%. Prior to this, analytical reagent grade pellets containing up to 2% carbonate were used to prepare the 40% KOH electrolyte. The standard irradiation period of 65 hours results in a total dose of  $7.2 \times 10^7$  rads ( $H_2O$ ).

Calibration of pressure transducers was performed before each run. The bath cells were checked by pressurization with nitrogen, while the cells to be irradiated were checked with argon. This resulted in modification of the gas atmosphere above the cell and made an estimate of oxygen take-up or evolution difficult. However, in these runs the presence of the cadmium electrodes also disturbs the oxygen content of the cells, so that the results do not represent the conditions to be encountered during operation with the silver-zinc system.

Gas samples were removed from the cell after test but before post-run capacities were measured. The gas chromatographic technique for

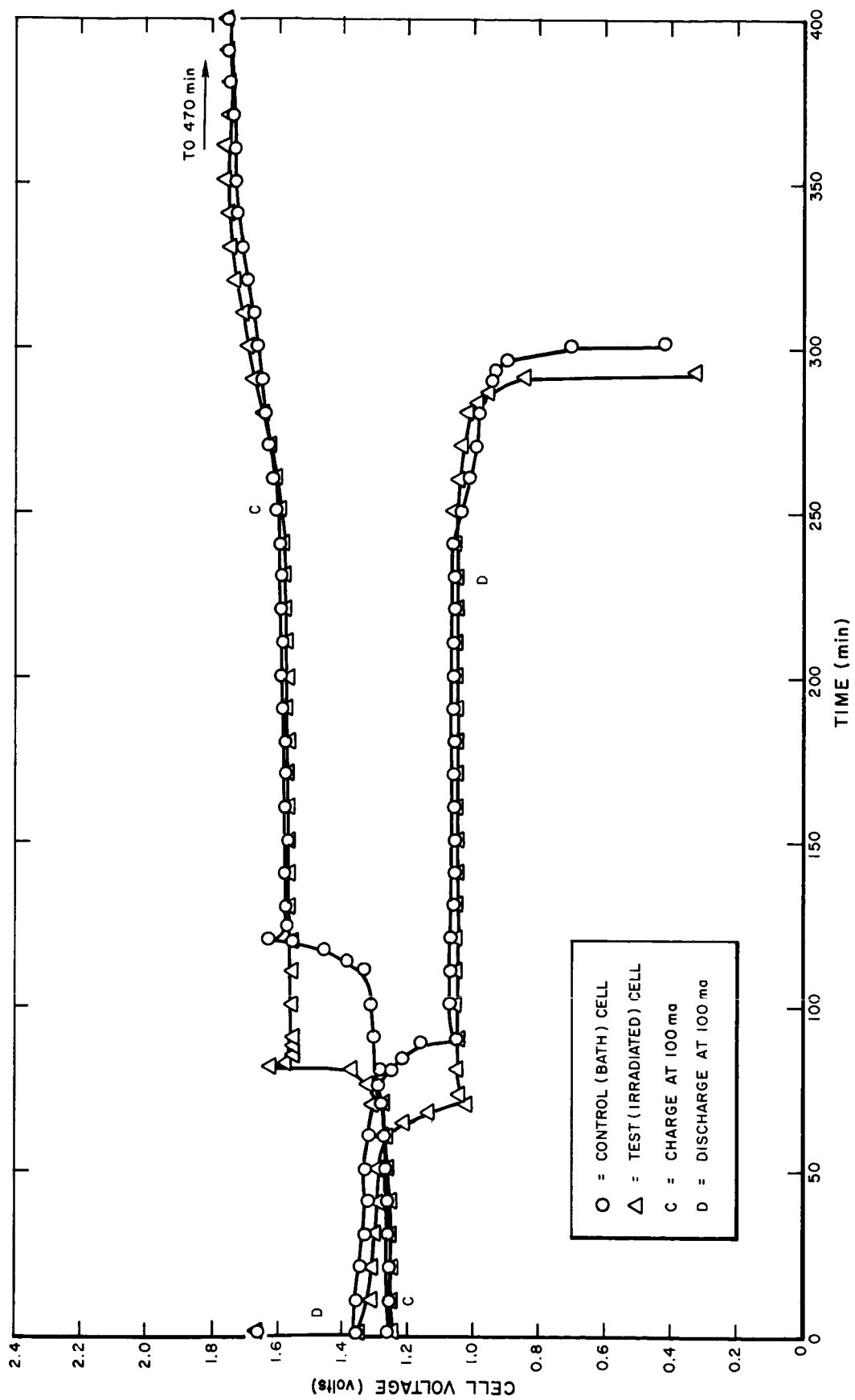


Figure 2. Charge and Discharge Curves for Ag-Cd Cells Prior to Irradiation Testing  
(Data for Run #CG-17)

analysis was supplemented by mass spectrometer measurements in several cases. The x-ray diffraction and x-ray fluorescence analyses of precipitated solids from the cells were supplemented by emission spectrographic analysis to determine  $\text{SiO}_2$  content in these precipitates.

#### IV. RESULTS

##### A. CAPACITY MEASUREMENTS

The cell configuration employing 2/3 or 1/2 of the supplied silver electrode coupled with two (cut) cadmium electrodes proved generally satisfactory in making the silver electrode capacity limiting. All capacity measurements were made at room temperature. A typical set of pre-run capacity data for both cells in a set (control bath and irradiation test), together with the corresponding post-test capacity data are shown in Table I. A complete tabulation of all measured cell capacity data is given in the Appendix. There is much apparently random variation of measured capacity, both before and after the testing under irradiation.

A summary of silver electrode capacity measurements for tests performed during this quarter is given in Table II. It should be noted that a complete electrode gives approximately 600 minutes (1 amp-hour) capacity, two-thirds of an electrode near 400 minutes (0.7 amp-hour), and one-half of an electrode yields about 300 minutes (0.5 amp-hour) capacity. Despite the use of controlled current power sources, the current was found to drift somewhat during these capacity measurements. This effect, due possibly to the high internal resistance of the three-compartment cells, probably caused some of the variation observed in successive determinations on a given electrode. However, as the irradiation test cell and the control cell were in series, the sets of data from each run should be comparable. Two other factors are also known to cause variation in electrode capacity,



and are likely to be operating here. These are (1) variation in properties from one electrode to another in any one lot, and (2) the effect of charge and discharge in changing the capacity of the silver electrode.

## B. MATERIAL LOSS

### 1. Preliminary Tests

In runs prior to Run #CG-10, when the silver electrodes were initially charged in a lucite cell with platinized platinum counter electrodes, a fine black precipitate accumulated at the bottom of the cell. During the charging period, the solution (40% KOH) darkened gradually, and the amount of precipitate appeared to increase. The precipitates formed when each of two silver electrodes was charged for 10 hours at 150 ma were found to weigh 9.6 and 4.0 mg, respectively. X-ray diffraction analyses showed the precipitate to contain no platinum. This charging process occurs under fluorescent light illumination.

To supplement the data on radiation induced precipitation of silver from KOH solutions exposed to charged silver electrodes, the following experiment was performed.  $\text{Ag}_2\text{O}$  was precipitated by addition of  $\text{AgNO}_3$  to an excess of a 40% KOH (aqueous) solution. Some of the clear, supernatant liquid was decanted after 30 minutes and an additional amount was decanted after 12 hours. These solutions were irradiated for various periods ( $\text{Co}^{60}$  gamma) and observations made at short intervals. Detectable precipitates were observed from both solutions after a gamma dose of only  $1.8 \times 10^4$  rads ( $\sim 0.05$  mg/ml solution).

## 2. Irradiation Results

The data obtained during both quarters of this program on material loss from the silver electrodes are shown in Table III. The values shown are calculated for a whole silver electrode. The losses were corrected for  $\text{SiO}_2$  content based on per cent Si as determined by emission spectrographic analyses. Table IV summarizes the average data for each state of charge tested.

X-ray diffraction and x-ray fluorescence analyses were made on all centrifuged residues. The data for this quarter from these analyses are shown in Table V. (Data from the first quarter are listed in the previous report.<sup>(2)</sup>) The cadmium, which evidently had diffused through the porous quartz separator, was present only as the hydroxide. Silver metal was always found as the major component in material from irradiated cells, with  $\text{Ag}_2\text{O}$  also detected in several cases. The bath runs differ in that an oxidized form of silver was usually detected in the sloughed material, in several cases as the major component.

### C. PRESSURE MEASUREMENTS AND GAS ANALYSES

A summary of the final measured cell pressures (at room temperature) is given in Table VI. A typical record of the continuously measured cell pressure during an irradiation (Run #CG-15) is shown in Figure 3. A small part of the initial pressure rise is due to the increase of cell temperature to nearly  $45^\circ\text{C}$  in the source. The single point, showing final pressure, was reached after the system had been removed from the  $\text{Co}^{60}$  source and returned to room temperature.

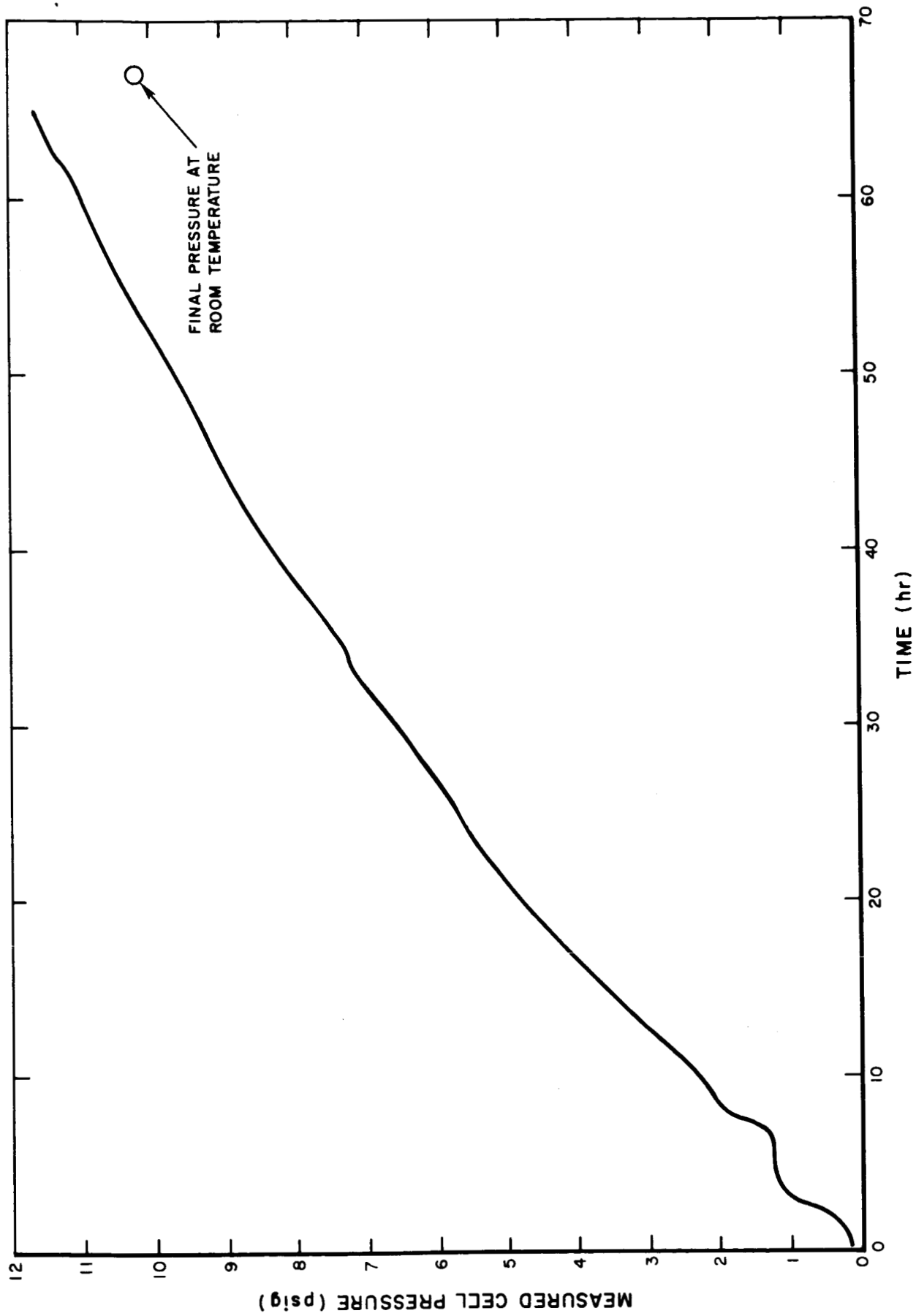


Figure 3. Course of Cell Pressure During Irradiation (Run #CG-15)

Results of gas chromatographic analyses and of mass spectrometric analyses of the gases removed from the cells after testing are summarized in Table VII. The evolution of H<sub>2</sub> during irradiation is noteworthy.

## V. DISCUSSION

### A. CAPACITY MEASUREMENTS

There is obviously much scatter in the data on measured electrode capacity (Table II and Appendix). This scatter arises partly from difficulties encountered in maintaining constant current during testing, partly from variations in properties from electrode to electrode, and partly, it is felt, from the nature of the silver electrode which is known to change its capacity during initial use.

With reservations, one may conclude that (a) the effects of radiation are small, no larger than 5 or 10%, (b) an increase in capacity at the higher states of charge (90% and 60% of full capacity) may be produced during irradiation, and (c) a corresponding decrease in capacity is produced with like treatment at lower (30%) state of charge.

It should be noted that results to date from cells on repeated short drain cycling (5% of capacity) indicate a drift toward cycling about an  $\text{Ag}_2\text{O}/\text{AgO}$  transition. This appears to occur in both irradiated and control cells, and at all initial states of charge investigated. It is not clear whether this is a true drift in state of charge due, for example, to unequal coulombic efficiencies during charging and discharge, or whether this  $\text{Ag}_2\text{O}/\text{AgO}$  transition establishes itself at any state of charge under the cycling regime employed. Further investigation will be required to clarify and explain this observation.

## B. MATERIAL LOSS

While the data are scattered (Tables III and IV), it appears that the radiation does cause significant loss of material from the silver electrode. Further, the loss appears to be greater in cells cycling at a 60% state of charge than at either 90% or 30%. It should be noted that some material loss does occur from mechanical agitation of the electrodes, though the amount so involved appears to be small compared to that produced on irradiation treatment.

While no conclusive proof has been obtained, the results during this report period appear to confirm the observations reported previously as to the mode of loss of material from the silver electrodes. Upon irradiation, silver is certainly precipitated as the metal from the electrolyte solution, possibly by reduction of dissolved or colloidal  $\text{Ag}_2\text{O}$  by H radicals. Most of the silver oxides, if any are dislodged from the electrode, would have to be chemically reduced to the metal (again by H radicals) as the metal is observed in the precipitated material as the major constituent. This reduction process could possibly prove troublesome if operating silver-zinc or silver-cadmium electrodes are employed in radiation fields, as the soluble silver oxides in the cell separator when reduced to silver metal may cause electrical shorting in the cell.

## C. GAS EVOLUTION

As noted above, the presence of the cadmium electrodes in the system does affect the amount of oxygen in the gas phase. However, the cadmium electrodes employed during this report period are not very effective in gettering oxygen and so are more nearly inert in this respect than the

impregnated porous plaque variety. In spite of this, it is possible that the greater reduction in oxygen content during irradiation than during operation of the control cell (cf. data for Run CG-20, Table VII) is associated with the irradiation process and not the cadmium electrode.

In all irradiation runs for which post-run gas analysis data are available, an evolution of hydrogen appears to have occurred (Table VII). This may result from reaction of the cadmium electrode with OH radicals, which then results in a net evolution of  $H_2$ . Tests in the absence of cadmium electrodes will be required to further investigate this effect.

#### D. RECOMMENDATION FOR FUTURE WORK

An effort will be made to obtain silver electrode capacity data containing less scatter so that effects of radiation can be made evident. Modifications of the electronic circuitry to produce a more constant current output during operation will be made. The effect of reducing current density at the silver electrode will be explored. Additional data obtained with these modifications outside the radiation field, both at room temperature and in a bath at radiation source temperature should enable one to isolate the effects due to radiation from all other effects.

Additional investigation of the effect of state of charge should be carried out. In particular, more data at 60 and at 30% of full charge should be obtained. Any effect of radiation on the silver electrode capacity should be studied as a function of total dose and dose rate, and other studies required to elucidate the mechanisms of observed effects should be carried out.

The effect whereby the cycling cell establishes itself at an  $\text{Ag}_2\text{O}/\text{AgO}$  transition should be confirmed, and the process whereby this is established should be elucidated.

A search will be made to obtain sturdier zinc electrodes so that their characteristics in the radiation field may be studied. This study should examine any effect of radiation on the capacity, the dendrite growth pattern, and on the deterioration processes in general occurring with irradiated zinc electrodes. The parameters of importance for this phase of the study should be state of charge, total dose, and dose rate.

Continued gas analyses after irradiation tests, coupled with tests of the gas evolution in cells with silver and zinc, and silver electrodes alone, should be performed and the results used to interpret the mechanism of gas evolution in irradiated silver-zinc cells.

Continuous pressure measurements will be made on both the bath and irradiated cells in the following phase of the study. Gas chromatographic analyses of the gases left in the cells will be made. From the results of the gas analyses, and with a consistent pattern of pressure changes during the irradiations, the mechanisms of the gas generation and utilization processes should be explored.



#### REFERENCES

1. "The Effects of Radiation on Nickel-Cadmium Battery Electrodes. I." Final Report, June 1963 to April 1965, AI-65-66.
2. "Radiation Effects on Silver and Zinc Battery Electrodes. I." Interim Report, April 1965 to July 1965, AI-65-158.

TABLE I. TYPICAL RESULTS OF SILVER ELECTRODE  
CAPACITY MEASUREMENTS  
(Data from Run #CG-12)

| Pre-Test Data                |                        | Post Test Data         |                        |
|------------------------------|------------------------|------------------------|------------------------|
| Irradiated Test Cell         | Control (Bath) Cell    | Irradiated Test Cell   | Control (Bath) Cell    |
| Capacity*<br>Cycle (minutes) | Capacity*<br>(minutes) | Capacity*<br>(minutes) | Capacity*<br>(minutes) |
| 1 303                        | 303                    | 295                    | 295                    |
| 2 325                        | 315                    | 320                    | 305                    |
| 3 315                        | 315                    | 265                    | 295                    |
| 4 ---                        | ---                    | 300                    | 322                    |

\*At a constant current of 100 ma.

TABLE II. SUMMARY OF SILVER ELECTRODE CAPACITY

| Run No.                    | Initial State<br>of Charge<br>(% of capacity) | Irradiated Cell               |                                |                 | Control (Bath) Cell           |                                |                 |
|----------------------------|---|-------------------------------|--------------------------------|-----------------|-------------------------------|--------------------------------|-----------------|
|                            |   | Pre-Test<br>Capacity<br>(min) | Post-Test<br>Capacity<br>(min) | Change<br>(min) | Pre-Test<br>Capacity<br>(min) | Post-Test<br>Capacity<br>(min) | Change<br>(min) |
| CG-9 <sup>(1)</sup>        | 90  | 627                           | 524 ± 4                        | -103            | 594                           | 551 ± 9                        | - 43            |
| -10                        | "   | 353 ± 0                       | 372 ± 7                        | + 19            | 390 ± 5                       | 405 ± 5                        | + 15            |
| -11 <sup>(2)</sup>         | "   | 359 ± 2                       | 376 ± 6                        | + 17            | 336 ± 9                       | 385 ± 37                       | + 49            |
| -15 <sup>(3)</sup>         | "   | 294 ± 6                       | 307 ± 7                        | + 13            | 258 ± 10                      | 263 ± 14                       | + 5             |
| -16                        | "   | 249 ± 4                       | 286 ± 12                       | + 37            | 276 ± 7                       | 276 ± 10                       | 0               |
| Avg. (Run CG-9 eliminated) |   |                               |                                | +7.4 ± 3.8      | Δ = +2.3%                     |                                | +5.1 ± 4.8      |
| CG-12                      | 60  | 314 ± 7                       | 295 ± 15                       | - 19            | 311 ± 5                       | 304 ± 9                        | - 7             |
| -13                        | "   | 333 ± 2                       | 334 ± 13                       | + 1             | 353 ± 13                      | 333 ± 13                       | - 20            |
| -14                        | "   | 331 ± 14                      | 365 ± 0                        | + 34            | 350 ± 15                      | 345 ± 0                        | - 5             |
| -17                        | "   | 274 ± 2                       | 273 ± 2                        | - 1             | 303 ± 4                       | 270 ± 3                        | - 33            |
| -18 <sup>(4)</sup>         | "   | 287 ± 5                       | 173 ± 8                        | -114            | 280 ± 14                      | 218 ± 4                        | - 62            |
| Avg. (CG-18I & C out)      |   |                               |                                | +1.1 ± 4.7      | Δ = +6.2%                     |                                | -5.1 ± 3.2      |
| CG-19                      | 30  | 298 ± 2                       | 241 ± 12                       | - 57            | 289 ± 3                       | 225 ± 3                        | - 64            |
| -20 <sup>(4)</sup>         | "   | 280 ± 6                       | 192 ± 23                       | - 88            | 269 ± 8                       | 195 ± 6                        | - 74            |
| -21                        | "   | 244 ± 1                       | 180 ± 5                        | - 64            | 233 ± 3                       | 202 ± 4                        | - 31            |
| Avg. (CG-20 out)           |   |                               |                                | -22.7 ± 3.6     | Δ = -5.0%                     |                                | -17.7 ± 4.4     |

(1) Only one set of pre-test capacities; these may be non-representative.

(2) Post test control data badly scattered.

(3) Post-test data may have been interchanged for irradiated and control cells.

(4) Solution in irradiated cell low after run due to spill.

(5) Capacity determined at a constant current of 100 ma.

TABLE III. MATERIAL LOSS IN SILVER ELECTRODE COMPARTMENT (1)

| Run                  | % State of Charge | Irradiated Cell                     |                          |                                | Control Cell                        |                          |                                |
|----------------------|-------------------|-------------------------------------|--------------------------|--------------------------------|-------------------------------------|--------------------------|--------------------------------|
|                      |                   | Total Wt. of Sloughed Material (mg) | Wt.%(2) SiO <sub>2</sub> | Net Wt. Sloughed Material (mg) | Total Wt. of Sloughed Material (mg) | Wt.%(2) SiO <sub>2</sub> | Net Wt. Sloughed Material (mg) |
| ZG-1                 | 90                | 42.8                                | 0.9                      | 42.4                           | 2.5                                 | ND                       | ----                           |
| ZG-5                 | "                 | 77.4                                | 0.9                      | 76.7                           | 36.0                                | ND                       | ----                           |
| ZG-6                 | "                 | 78.5                                | 1.3                      | 77.5                           | 11.2                                | ND                       | ----                           |
| CG-7                 | "                 | 50.4                                | 0.4                      | 50.2                           | 1.3                                 | ND                       | ----                           |
| CG-8                 | "                 | 50.6                                | 4.2                      | 48.5                           | 9.6                                 | 4.2                      | 9.2                            |
| CG-9 <sup>(3)</sup>  | "                 | 54.7                                | 4.2                      | 52.4                           | 4.1                                 | 4.2                      | 3.9                            |
| CG-10                | "                 | 68.8                                | 4.2                      | 65.9                           | 11.8                                | 2.1                      | 11.6                           |
| CG-11                | "                 | 55.4                                | 4.2                      | 52.9                           | 6.1                                 | 8.4                      | 5.6                            |
| CG-13                | 60                | 109.7                               | 31.5                     | 75.2                           | 24.6                                | 12.6                     | 21.5                           |
| CG-14                | "                 | 109.8                               | 31.5                     | 75.2                           | 20.7                                | 12.6                     | 18.1                           |
| CG-15                | 90                | 77.0                                | 2.1                      | 75.4                           | 17.2                                | 12.6                     | 15.0                           |
| CG-16                | "                 | 47.6                                | 2.1                      | 46.6                           | 26.2                                | 42.0                     | 15.2                           |
| CG-18                | 60                | 88.3                                | 6.3                      | 82.7                           | 39.4                                | 6.3                      | 28.5                           |
| CG-19                | 30                | 58.4                                | 12.6                     | 51.0                           | 23.4                                | 4.2                      | 22.4                           |
| CG-20 <sup>(4)</sup> | 30                | 79.9                                | 31.5                     | 54.7                           | 74.6                                | 4.2                      | 71.5                           |

(1) Weights normalized to correspond to a whole silver electrode.

(2) Wt. % SiO<sub>2</sub> calculated from Wt. % Si in material as determined by emission spectrography.

(3) Total gamma dose =  $9.8 \times 10^{-7}$  rads; all others =  $7.2 \times 10^7$  rads.

(4) Material was observed to become detached from the control (bath) silver electrode during cell assembly.

ND = Not determined.

TABLE IV. SUMMARY OF SILVER ELECTRODE MATERIAL LOSS DATA:  
SILVER-CADMIUM CELLS

(Gamma Dose =  $7.2 \times 10^7$  rad ( $H_2O$ ) )

| State of Charge<br>(%) | Average Wt. of Sloughed Material <sup>(1)</sup><br>(mg) |                |
|------------------------|---|----------------|
|                        | Irradiated Cell   | Control Cell   |
| 90                     | $52.8 \pm 5.3^{(2)}$                                    | $11.3 \pm 3.1$ |
| 60                     | $77.7 \pm 3.3$  | $22.7 \pm 3.9$ |
| 30                     | $52.9 \pm 1.9$  | $22.4^{(3)}$   |

(1) Corrected for  $SiO_2$  content.

(2) Data from Run CG-15 omitted.

(3) Only one datum included.

TABLE V. X-RAY DIFFRACTION AND FLUORESCENCE ANALYSES  
OF RESIDUAL MATERIAL FROM THE SILVER ELECTRODE COMPARTMENT

| Run         | Detected by <sup>(1)</sup><br>X-Ray Diffraction                          | Determined by X-Ray Fluorescence<br>(Wt. Ratio: as elements) |
|-------------|--|--|
|             |  | Cd/Ag  |
| CG-10-Irrad | Ag   | 0.024  |
| CG-10-Bath  | Ag, Cd(OH) <sub>2</sub>  | 1.04   |
| CG-11-Irrad | Ag   | 0.012  |
| CG-11-Bath  | Ag, Ag <sub>2</sub> O  | 0.026  |
| CG-12-Irrad | Ag   | 0.064  |
| CG-12-Bath  | Ag, Ag <sub>2</sub> Fe <sub>2</sub> O <sub>4</sub>                       | 0.042  |
| CG-13-Irrad | Ag, Cd(OH) <sub>2</sub> , SiO <sub>2</sub>                               | 0.064  |
| CG-13-Bath  | Ag   | 0.075  |
| CG-14-Irrad | Ag, Cd(OH) <sub>2</sub>  | 0.18   |
| CG-14-Bath  | Ag <sub>2</sub> , Fe <sub>2</sub> O <sub>4</sub> , Ag                    | 0.15   |
| CG-15-Irrad | Ag, Cd(OH) <sub>2</sub>  | 0.017  |
| CG-15-Bath  | Ag, Cd(OH) <sub>2</sub>  | 0.23   |
| CG-16-Irrad | Ag, Cd(OH) <sub>2</sub> , Ag <sub>2</sub> O                              | 0.41   |
| CG-16-Bath  | Cd(OH) <sub>2</sub> , Ag, Ag <sub>2</sub> Fe <sub>2</sub> O <sub>4</sub> | 0.39   |
| CG-17-Irrad | Ag, SiO <sub>2</sub> , Ag <sub>2</sub> O                                 | 0.020  |
| CG-17-Bath  | Ag <sub>2</sub> O, Ag  | 0.017  |
| CG-18-Irrad | Ag   | 0.019  |
| CG-18-Bath  | Ag, Ag <sub>2</sub> O  | 0.020  |
| CG-19-Irrad | Ag   | 0.012  |
| CG-19-Bath  | Ag <sub>2</sub> O, Ag, SiO <sub>2</sub>                                  | 0.012  |
| CG-20-Irrad | Ag   | 0.031  |
| CG-20-Bath  | AgO, Ag <sub>2</sub> O   | 0.031  |

(1) Major constituent listed first

TABLE VI. FINAL CELL PRESSURE<sup>(1)</sup>

| Run No. | Nominal<br>State of<br>Charge (%) | Gauge Pressure<br>(mm) |                     |
|---------|-----------------------------------|------------------------|---------------------|
|         |                                   | Irrad. Cell            | Control (Bath) Cell |
| CG-10   | 90                                | (2)                    | +55                 |
| CG-11   | 90                                | (3)                    | (3)                 |
| CG-12   | 60                                | +408                   | (3)                 |
| CG-13   | 60                                | +209                   | (4)                 |
| CG-14   | 60                                | +400                   | +54                 |
| CG-15   | 90                                | +524                   | (5)                 |
| CG-16   | 90                                | +415                   | +224                |
| CG-17   | 60                                | +498                   | +16                 |
| CG-18   | 60                                | (4)                    | (4)                 |
| CG-19   | 30                                | +120                   | -40                 |
| CG-20   | 30                                | +255                   | -85                 |
| CG-21   | 30                                | (4)                    | (4)                 |

## Notes:

- (1) Measured with cell at room temperature.
- (2) Pressure exceeded the range of the transducer.
- (3) No measured value; transducer circuitry problems.
- (4) Pressure not measured.
- (5) Cell leaked gas.

TABLE VII. ANALYSES OF GASES REMOVED FROM CELLS AFTER TESTING

| Run No. | Cell  | Nominal    |                 | Sample Volume (ml) | Total Pressure (mm Hg) | Analysis Method & Sample Number | Volume %       |                     |                     |       |                 |                     |                       |                 |
|---------|-------|------------|-----------------|--------------------|------------------------|---------------------------------|----------------|---------------------|---------------------|-------|-----------------|---------------------|-----------------------|-----------------|
|         |       | Charge (%) | State of Charge |                    |                        |                                 | H <sub>2</sub> | O <sub>2</sub>      | N <sub>2</sub>      | CO    | CH <sub>4</sub> | Ar                  | Other                 | G <sub>H2</sub> |
| CG-16   | Irrad | 90         |                 | 41.5               | 1208                   | GC-1                            | 52.8           | 0.26                | 19.3                | 0.15  | 0.07            | 28.4 <sup>(1)</sup> |                       | 0.27            |
| CG-16   | Bath  | 90         |                 | 23.7               | 984                    | GC-1                            | 0.14           | 20.3                | 78.4 <sup>(2)</sup> | ND    | ~0.001          | 0.41                |                       | ----            |
| CG-17   | Irrad | 60         |                 | 36.5               | 988                    | GC-1                            | 15.1           | 0.35                | 55.6                | 0.32  | 0.04            | 30.4 <sup>(1)</sup> | CO <sub>2</sub> =0.31 | 0.056           |
| CG-17   | Bath  | 60         |                 | 35.5               | 971                    | GC-1                            | 0.10           | 0.97                | 98.3 <sup>(2)</sup> | <0.01 | 0.02            | 0.87                | CO <sub>2</sub> =0.39 | ----            |
| CG-19   | Irrad | 30         |                 | 46.4               | 540 <sup>(3)</sup>     | GC-1                            | 16.9           | 9.9                 | 70.8                | ----  | ----            | ----                |                       | ----            |
|         |       |            |                 |                    |                        | GC-2                            | ----           | 10.9 <sup>(4)</sup> | 71.2                | 1.0   | 0.7             |                     |                       | ----            |
| CG-19   | Bath  | 30         |                 | 47.4               | 700                    | MS-1                            | 17.5           | 9.79                | 71.4                | 0.64  | 0.32            | 0.58                | CO <sub>2</sub> =0.11 | ----            |
|         |       |            |                 |                    |                        | GC-1                            | 0.05           | 16.5                | 82.7                | ----  | ----            | ----                |                       | ----            |
|         |       |            |                 |                    |                        | GC-2                            | ----           | 16.7 <sup>(4)</sup> | 83.4                | 0.41  | 0.005           | ----                |                       | ----            |
| CG-20   | Irrad | 30         |                 | 47.9               | 779                    | MS-1                            | 0.07           | 13.7                | 85.6                | 0.40  | 0.02            | 0.82                | CO <sub>2</sub> =0.14 |                 |
|         |       |            |                 |                    |                        | GC-1                            | 27.4           | 1.2                 | 70.2                | ----  | ----            |                     | He<0.005              | 0.099           |
|         |       |            |                 |                    |                        | GC-2                            | ----           | 1.3                 | 72.6                | 0.3   | 0.4             |                     |                       |                 |
| CG-20   | Bath  | 30         |                 | 53.0               | 655                    | GC-1                            | 0.19           | 10.3                | 88.9                | ----  | ----            |                     | He<0.01               | ----            |
|         |       |            |                 |                    |                        | GC-2                            | ----           | 10.8                | 89.3                | 0.15  | <0.02           |                     |                       |                 |

Notes:

- (1) Ar used to calibrate pressure transducer prior to irradiation.
- (2) N<sub>2</sub> used to calibrate pressure transducer prior to test.
- (3) Evidence for leak at valve when connected to evacuate prior to gas chromatographic analysis.
- (4) Combined O<sub>2</sub> + Ar.

ND = Not detected  
GC = Gas chromatography  
MS = Mass spectrometry



APPENDIX  
SILVER ELECTRODE (CELL) CAPACITY MEASUREMENTS<sup>(1)</sup>

| Run No. | State of Charge | Cycle No. | Pre-Test Data    |                     | Post-Test Data     |                     |
|---------|-----------------|-----------|------------------|---------------------|--------------------|---------------------|
|         |                 |           | Irrad. Test Cell | Control (Bath) Cell | Irrad. Test Cell   | Control (Bath) Cell |
| CG-9    | 90              | 1         | 627              | 594                 | 527                | 560                 |
|         |                 | 2         | ---              | ---                 | 520                | 542                 |
| -10     | 90              | 1         | 353              | 395                 | 365                | 410                 |
|         |                 | 2         | 353              | 385                 | 378                | 400                 |
| -11     | 90              | 1         | 360              | 355                 | 385                | 330                 |
|         |                 | 2         | 355              | 325                 | 373                | 405                 |
|         |                 | 3         | 360              | 335                 | 370                | 420                 |
|         |                 | 4         | 360              | 330                 | ---                | ---                 |
| -12     | 60              | 1         | 303              | 303                 | 295                | 295                 |
|         |                 | 2         | 325              | 315                 | 320                | 305                 |
|         |                 | 3         | 315              | 315                 | 265                | 295                 |
|         |                 | 4         | ---              | ---                 | 300                | 322                 |
| -13     | 60              | 1         | 330              | ---                 | 356                | 353                 |
|         |                 | 2         | 335              | 365                 | 337                | 337                 |
|         |                 | 3         | 335              | 340                 | 325                | 323                 |
|         |                 | 4         | ---              | ---                 | 317                | 317                 |
| -14     | 60              | 1         | 317              | 335                 | 365                | 345                 |
|         |                 | 2         | 345              | 365                 | 365                | 345                 |
| -15     | 90              | 1         | 303              | 274                 | 317                | 287                 |
|         |                 | 2         | 295              | 258                 | 310                | 265                 |
|         |                 | 3         | 285              | 243                 | 305                | 243                 |
|         |                 | 4         | ---              | ---                 | 295                | 255                 |
| -16     | 90              | 1         | 253              | 280                 | 303                | 291                 |
|         |                 | 2         | 250              | 283                 | 281                | 273                 |
|         |                 | 3         | 243              | 265                 | 273                | 265                 |
| -17     | 60              | 1         | 290              | 300                 | 275                | 270                 |
|         |                 | 2         | 275              | 298                 | 275                | 275                 |
|         |                 | 3         | 275              | 305                 | 273                | 270                 |
|         |                 | 4         | 273              | 310                 | 268                | 265                 |
|         |                 | 5         | 271              | 304                 | ---                | ---                 |
| -18     | 60              | 1         | 280              | 268                 | 185 <sup>(2)</sup> | 215                 |
|         |                 | 2         | 293              | 273                 | 175                | 220                 |
|         |                 | 3         | 288              | 298                 | 165                | 213                 |
|         |                 | 4         | ---              | ---                 | 165                | 225                 |
| -19     | 30              | 1         | 296              | 286                 | 222                | 230                 |
|         |                 | 2         | 300              | 291                 | 255                | 225                 |
|         |                 | 3         | ---              | ---                 | 245                | 220                 |
| -20     | 30              | 1         | 272              | 257                 | 162 <sup>(2)</sup> | 183                 |
|         |                 | 2         | 287              | 280                 | 176                | 195                 |
|         |                 | 3         | 282              | 270                 | 208                | 200                 |
|         |                 | 4         | ---              | ---                 | 222                | 202                 |
| -21     | 30              | 1         | 230              | 173                 | 125                | 198                 |
|         |                 | 2         | 245              | 230                 | 170                | 204                 |
|         |                 | 3         | 243              | 235                 | 185                | 208                 |
|         |                 | 4         | ---              | ---                 | 185                | 202                 |
|         |                 | 5         | ---              | ---                 | 180                | 196                 |

(1) Capacity determined at a constant current of 100 ma.

(2) Solution level low after run due to spill during test.

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